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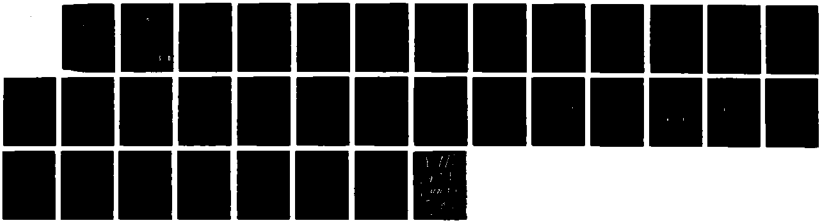

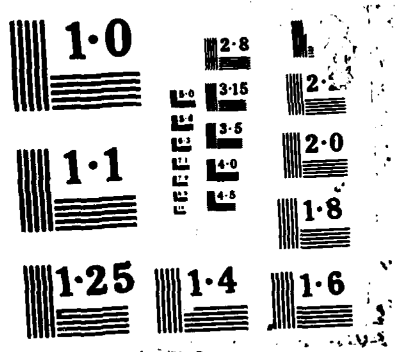
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# AN INVESTIGATION OF THE F-14A DEPARTURE/ FLAT SPIN ENVIRONMENT AS SIMULATED BY THE DYNAMIC FLIGHT SIMULATOR


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16 AUGUST 1987

FINAL REPORT

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An evaluation of the F-14A departure/flat spin environment, as simulated by the Dynamic Flight Simulator (DFS), was conducted to determine the capability of F-14 pilots to complete NATOPS spin recovery procedures. The evaluation was performed in both fixed and moving base (dynamic) modes using standard qualitative and quantitative flight test techniques. Nineteen F-14A U.S. Navy fleet aviators participated in this study and experienced departures and fully-developed flat spins ranging from 2 to 5 G's eyeballs out ( forces on the pilot from back to front; -Gx). The objectives of the experiment were to (1) Determine the effects of Roll Stability Augmentation System (Roll SAS) ON/OFF, aircraft loading, and asymmetric thrust on the severity of simulated F-14A aircraft departure/spin entry; and (2) Determine the effect of increased throttle friction, Roll SAS, harness lock, and -Gx on the pilot's capability to recover the simulated F-14A aircraft from a departure/flat spin. The time/altitude loss data and pilot questionnaire data, indicate that the optimal recovery aid is the locking of the harness, with Roll SAS activation and throttle friction remaining as secondary recovery aids. In addition, the most severe spin and departure entries occurred under asymmetric thrust con-

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ABSTRACT

An evaluation of the F-14A departure/flat spin environment, as simulated by the Dynamic Flight Simulator (DFS), was conducted to determine the capability of F-14 pilots to complete NATOPS spin recovery procedures. The evaluation was performed in both fixed and moving base (dynamic) modes using standard qualitative and quantitative flight test techniques. Nineteen F-14A U.S. Navy fleet aviators participated in this study and experienced departures and fully-developed flat spins ranging from 2 to 5 G's eyeballs out (forces on the pilot from back to front; -Gx). The objectives of the experiment were to (1) Determine the effects of Roll Stability Augmentation System (Roll SAS) ON/OFF, aircraft loading, and asymmetric thrust on the severity of simulated F-14A aircraft departure/flat spin entry; and (2) Determine the effect of increased throttle friction, Roll SAS, harness lock, and -Gx on the pilot's capability to recover the simulated F-14A aircraft from a departure/flat spin. The time/altitude loss data, and pilot questionnaire data, indicate that the optimal recovery aid is the locking of the harness, with Roll SAS activation and throttle friction remaining as secondary recovery aids. In addition, the most severe spin and departure entries occurred under asymmetric thrust conditions. Entries with aircraft loading and/or the Roll SAS activated followed asymmetric thrust closely in contributing to entry severity.

# INTRODUCTION

## BACKGROUND

Tactical aircraft flight simulators have generally lacked realism in the manuevering environment. The high forces characteristic of tactical manuevering are difficult to simulate with conventional motion base schemes. Physical limits on allowable displacements of conventional motion base simulators restrict the magnitude and duration of the forces used for manuevering cues. The inability of conventional flight simulators to produce representative force cues detracts from the realism of the simulation, particularly for out-of-control flight phases, such as the departure/spin phase.

For this reason, the Naval Air Development Center (NAVAIRDEVCEN) has developed a total G-force simulation capability utilizing the Dynamic Flight Simulator (DFS). Using the NAVAIRDEVCEN's human centrifuge as a motion and force base, the DFS is designed to be capable of reproducing the total multidirectional (i.e., 6 degrees-of-freedom) G-force environment of modern high performance aircraft. The DFS is a safe platform for evaluating new concepts in crew station design, cockpit displays and controls, restraint systems, aerodynamic configurations and handling qualities as well as conducting pilot familiarization with procedures in the G-environment. The DFS is currently configured to simulate the F-14A aircraft flight environment.

The F-14 has been shown to exhibit a flat spin mode with yaw rates and longitudinal accelerations in excess of 150 deg/sec and negative 5 Gx (eyeballs-out), respectively, at the pilot's station (reference (1)). Such conditions are extremely difficult to safely investigate in the real aircraft but are well suited to centrifuge simulation. To provide insight into this problem the DFS has been configured as an F-14A aircraft, including F-14A cockpit ergonomics and aerodynamics. The initial investigations conducted with the DFS in the departure/spin environment have proven it's capability and fidelity (reference (2)).

## PURPOSE

The purpose of this program was to 1) Determine the effects of Roll Stability Augmentation System (Roll SAS) ON/OFF, aircraft loading, and asymmetric thrust on the severity of simulated F-14A aircraft departure/flat spin entry; and 2) Determine the effect of increased throttle friction, Roll SAS, harness lock, and -Gx on the pilot's capability to recover the simulated F-14A aircraft from a departure/flat spin.

This paper presents the results obtained and provides recommedations concerning departure/flat spin entry and recovery.

## DESCRIPTION OF DFS

The DFS is a complete flight simulation facility which is capable of operating independently or as an integral part of the NAVAIRDEVCEN Human Centrifuge. The unique force and motion generating capabilities of the

centrifuge produce a three-degree-of-freedom man-rated motion base for the DFS. The centrifuge includes a 10-foot diameter gondola, whose angular rotation is controlled by a two-gimbal drive system, mounted at the end of a 50-foot arm. This motion system is capable of attaining a 10 G/sec onset rate between 1.5 and 15 G's and accelerating a typical one ton cockpit plus subject and peripheral equipment to 15 G's.

The crewstation installed in the gondola consists of a multipurpose cockpit, a removable instrument panel display, and an over-the-nose computer generated real world visual display unit. The crewstation for this experiment was configured to represent the F-14A aircraft. Information is displayed to the pilot in the crewstation via simulated aircraft instruments and programmable Collins color cockpit displays. Pilot control of the DFS is accomplished via a McFadden, hydraulic, three-axis control loader system (stick and rudder) and an F-14 throttle assembly. The crewstation and gondola system communicate with the Center's CDC Cyber 170/760 digital computer system, via a fiber optic link, to provide the necessary real-time simulation computational requirements. The centrifuge control is accomplished via an EAI 231R analog computer (reference (3)).

The DFS utilizes F-14A aerodynamic data and control software packages, which provide flight control, and engine instrumentation algortihms for the simulation. The algorithms encompass the full non-linear, six degree of freedom, rigid body equations of motion of the F-14A aircraft and are designed to accomodate large angular orientations; mass, engine and store asymmetries; and classical as well as primary rotary balance (aircraft rotary balance as a function of angle-of-attack and rotation rate only), stability and control derivatives. The F-14A configuration variations available for this experiment included a clean aircraft (no stores loaded) and a 2X4 loaded aircraft ( two of each: AIM-7, AIM-9, AIM-54A, drop fuel tanks ), configuration each in the cruise mode (landing gear and flaps up) with automatic manuevering flaps and slats. The stablility and control derivatives of each of the configurations cover a range of 0 to 90 degrees angle-of-attack for Mach numbers less than or equal to 0.6, and 0 to 30 degrees angle-of-attack between Mach 0.6 and Mach 0.9. In addition, the low-speed data (Mach < 0.6) of each of the configurations incorporates the effects of sideslip angles of up to $\pm$ 20 degrees. Data is not included in either configuration's data package/mathematical model for Mach numbers in excess of 0.9, or for angle-of-attack values of less than zero. DFS aircraft conditions such as stall susceptibility or real-world gaming area radius can be modified without reprogramming or restarting the control software, which allows flexibility in experiment structure.

The DFS can be operated in a number of modes ranging from fixed-based to fully-dynamic. The cockpit, when removed from the gondola may be operated as a purely fixed-based simulator, with all simulated aircraft systems functional. A static or fixed-based mode is also available with the cockpit installed in the gondola prior to energizing the centrifuge. The next mode of operation is the gimbals-only mode which provides limited motion with all centrifuge sytems but the centrifuge arm energized. The limited motion of this mode consists of limited pitch and roll motions

without the accompanying G-profiles. The final mode of operation is the fully-dynamic mode which requires full energization of the centrifuge.

The DFS, since it uses the centrifuge as a motion base, exhibits some unique sensations. The centrifuge simulates 1 G aircraft flight by rotating at a 1.55 G platform, as shown in Figure 2. The rotation of the centrifuge in combination with some pilot's head movements will produce such sensations as a severe left rolling sensation when the pilot rotates his head left with a downward tilt (reference (5)). In order to minimize the effect of these sensations, all pilots are discouraged from making any unnecessary head movements. This limitation on movement makes the the DFS unsuitable for air combat manuevering and formation flying, although it provides an extremely realistic simulation of the cockpit environment during out-of-controlled flight.

## F-14A SPIN EXPERIMENT METHODOLOGY

### SCOPE

Operational capabilities and limitations, as well as the available aerodynamic models, served to impact the scope of this F-14A spin experiment. Thus, the clean configuration (i.e., no exterior loading) and a critical stores configuration (two of each: AIM-7, AIM-9, AIM-54A, drop fuel tanks), commonly referred to as the 2X4 loaded aircraft, were evaluated during departures/flat spins. Tests were conducted under Roll SAS ON or OFF, and balanced or asymmetric thrust conditions. Dynamic operational limits imposed by structural, safety and physiological considerations are presented in Table 1.

Table 1: DFS Centrifuge Limitations

| | | |
|---|---|---|
| Longitudinal Acceleration | - Gx | ± 6 G's |
| Lateral Acceleration | - Gy | ± 1 G's |
| Normal Acceleration | - Gz | + 6 G's |
| Acceleration Onset Rate | | ± 2.5 G/sec |
| Maximum Gimbal Rate | | ± 30 deg/sec |

### SUBJECTS

The F-14A Spin Experiment was performed by nineteen F-14A U.S. Navy fleet aviators, from various east and west coast squadrons. A list of these participants is presented in Table 2. Each aviator who participated experienced a half an hour static and dynamic familiarization (phase 1 & 2) and one hour of fully-dynamic data collection (phase 3).

The familiarization and data collection phases were conducted on separate days to enhance the participants acclimitization to the centrifuge motion system and it's inherent Coriolis forces.

Table 2: F-14A Spin Experiment Participants Oct 1986

| RANK: | NAME: | SQUADRON: |
|---|---|---|
| LT | W. M. ANDERSON | VF-103 |
| LT | T. L. BEHAM | VF-114 |
| LT | W. M. DAVIDSON | VF-33 |
| LT | J. A. FIRANZI | VF-33 |
| LT | W. W. GILDNER | VF-211 |
| LT | M. D. HAMELE | VF-33 |
| LT | S. W. JOHNSON | VF-211 |
| LT | B. KENISON | VF-114 |
| LT | J. T. LINDGREN | VF-33 |
| CDR | J. F. MCFILLIN | VF-103 |
| LT | M. MOLIDAR | VF-33 |
| LCDR | B. V. MUHLENBERG | VF-124 |
| LCDR | J. K. NAWROCKI | VF-126 |
| LCDR | R. E. NORRIS | VF-101 |
| LT | D. W. SCHLICKENMEYER | VF-33 |
| LCDR | T. L. SPILMAN | VF-33 |
| LCDR | T. TINSLEY | VF-126 |
| LCDR | S. VAUGHN | VF-102 |
| LTJG | A. WILLIAMS | VF-74 |

PROCEDURE

The experiment was conducted in both static and dynamic modes. Each pilot performed seven manuevers during the three phases of the experiment. The manuevers were three standard manuevers and four types of departures and spins. The three standard manuevers were a 3 G level turn (both right and left), a 4 G loop, and a split "S", which demonstrated to the pilot the performance quality of the DFS relative to the F-14A aircraft. The four types of departures and spins performed during this experiment were:

1) Departure - Unaccelerated Entry :
The pilot decelerated and pulled the aircraft nose up to approximately 30 deg angle-of-attack (AOA), and 120 kts then initiated full aft stick, full rudder deflection in the desired direction of the departure and full lateral stick deflection opposite to the rudder input (cross-control). The pilot held these controls until he recognized the departure, then recovered the aircraft according to NATOPS instructions.

2) Departure - Accelerated Entry:
The pilot performed a 3 G level turn (250 kts) in the direction of the departure and applied full bottom rudder and aft stick with lateral deflection opposite to the rudder input (cross-control). The pilot held these controls until he recognized the departure, then recovered the aircraft according to NATOPS instructions.

3) Spin - Unaccelerated Entry:
The pilot performed an unaccelerated departure, held controls until the desired yaw rate or G-force was obtained, then recovered the aircraft using NATOPS spin recovery procedures and notes.

4) Spin - Accelerated Entry:
The pilot performed an accelerated departure entry, held controls until the desired yaw rate or G-force was obtained, then recovered the aircraft using NATOPS spin recovery procedures and notes.

Phase one, the static familiarization phase, required the pilots to perform the three standard manuevers (i.e., 3 G turns, 4 G loop, and split "S") as well as the departure/spin entries presented in Table 3. During this phase, the pilot gained experience in DFS operational procedures and manuevers. Phase two, the dynamic familiarization phase, required the pilots to perform the same manuevers as in the static phase, but under the G-environment of the centrifuge. Upon completion of this phase the pilots were acclimated to the centrifuge motion environment. Once the familiarization phases were completed the pilots began phase three, the dynamic data collection phase. The dynamic data collection phase required the pilot to perform ten manuevers under various aircraft conditions as presented in the Test Matrix (Figure 1).

Table 3: Departure and Spin Familiarization Manuevers

| | | |
|---|---|---|
| (1) | Right Departure; | Unaccelerated Entry |
| (2) | Left Departure ; | Accelerated Entry |
| (3) | Right Spin; | Unaccelerated Entry, Gx=-2 G's/yaw rate=96 deg/sec |
| (4) | Left Spin; | Accelerated Entry, Gx=-2 G's/yaw rate=96 deg/sec |
| (5) | Right Spin; | Unaccelerated Entry with Engine Stall; Gx=-3 G's/yaw rate=117 deg/sec |

Experiment instrumentation and data collection consisted of simulated cockpit instruments, stopwatch, and three 8-channel strip chart recorders. Data was also displayed digitally on the project officers display and on the data display terminal in the Experiment Control Station. All dynamic centrifuge operations were conducted under the guidance of a biomedical team, who maintained visual and voice communication with the pilot and continually monitored his heart-beat, pulse rate, and blood pressure.

Pilot opinions were gathered by means of a post-flight questionnaire (Appendix A). This questionnaire was administered to each pilot following completion of the dynamic data collection phase. Questions included on the questionnaire addressed departure entry severity, flat spin entry severity, flat spin recovery, and general information. A five point scale, with five being the maximum rating (i.e., mild 1 2 3 4 5 severe), was used to quantify pilot responses to each question. For analysis purposes these

individual ratings were averaged to find a cumulative pilot rating (average pilot rating) of each questionnaire item, additionally the raw data was analyzed for trends and specific data point collection.

## RESULTS AND DISCUSSIONS

### DYNAMIC FLIGHT SIMULATOR SPIN FIDELITY

The F-14 has been shown to exhibit a flat spin mode with yaw rates and longitudinal accelerations in excess of 150 deg/sec and negative 5 Gx (eyeballs-out), respectively. The DFS exposes the pilots to the realistic forces of F-14A departures and flat spins, through it's aerodynamic model and centrifuge motion. Typical spin and departure simulation experiences are shown in Figures 3 and 4, respectively. The following are two typical pilot comments on DFS spin fidelity:

> "Very sensitive to roll inputs, however this has little/any effect on spin recoveries themselves."

> "Once you got used to the artificialities of the DFS, it was relatively easy to imagine you were actually in a spinning aircraft."

### ENTRY CONDITION EFFECTS

One of the objectives of this experiment was to investigate the effect of various aircraft conditions on depature and flat spin severity. For this experiment, a departure was defined as a departure from controlled flight (i.e., aircraft responses are no longer predictable or controllable by flight control inputs). Pilot recognition of a departure was characterized by the angle-of-attack remaining pegged at 30 units and yaw rates of approximately 20 - 30 deg/sec. The departure phase of this experiment varied the following aircraft conditions: Roll SAS ON/OFF (OFF - standard flight condition), Asymmetric Thrust, and 2X4 loading of the aircraft. Analysis of pilot questionaire (Appendix A) subjective data showed that for departures:

1) Of all these conditions investigated, asymmetric thrust aggravated the departure the most ( 3.6 avg. pilot rating).

2) 2X4 Loading increased the severity of departures (3.1 avg. pilot rating), more than Roll SAS ON did but not as much as asymmetric thrust.

3) Roll SAS ON created a more severe departure than Roll SAS OFF, the normal flight condition ( 3.0 vs. 2.3 avg. pilot rating respectively), but was not as severe as either asymmetric thrust or the 2X4 loading.

The objective measure of severity used for this experiment was the aircraft's departure entry time; a high entry time for mild departure and a low entry time for a severe departure. The entry times/severity of each

experimental departure condition, shown in Figure 5, correlate well with the pilot ratings for each aircraft condition.

The flat spins of the experiment, were performed by the pilots holding departure/pro-spin controls until a pre-determined yaw rate was obtained, and were conducted utilizing variations in aircraft loading and balanced thrust versus asymmetric thrust. The most severe spin entries were the result of asymmetric thrust (4.5 avg. pilot rating) followed by the 2X4 aircraft configuration (3.8 avg. pilot rating). The least severe spins were developed in a clean aircraft configuration (3.3 avg. pilot rating), as corresponds with the results of the departure phase shown in Figure 5. All pilots were capable of safely recovering their simulated aircraft from the gamut of departures and spins.

RECOVERY

The definition of departure/spin recovery used for this experiment was a yaw rate of 0 deg/sec, increasing airspeed, and regaining straight and level flight before reaching 10,000 feet. This experiment's DFS flat spin missions were all started at 30,000 feet and 184 knots. This high altitude allowed the pilot sufficient altitude to initiate and recover a flat spin before reaching the minimum altitude of 10,000 feet.

The departures experienced during this experiment were recovered from by following NATOPS recovery procedures (reference (4)):

1) Stick - Forward/Neutral Lateral
2) Harness - Lock
3) Rudder - Opposite Turn Needle/Spin Arrow

If NO Recovery:

4) Stick - Into Turn Needle
5) If engine stalls both throttles to IDLE

If Recovery Indicated:

6) Controls- Neutral
7) Recover at 17 units AOA (angle-of-attack)

Departure recovery was so quickly attained by all pilots when NATOPS procedures were followed that no further investigation in that area was conducted during this experiment, full concentration was focused on the F-14A flat spin recovery problem.

The flat spin recovery procedures successfully followed during this experiment were NATOPS procedures (reference (4)) with a slight interpretation:

1) Stick - Forward/Neutral Lateral
2) Harness - Lock
3) Rudder - Opposite Turn Needle/Spin Arrow
4) If engine stalls both throttles to IDLE

If NO Recovery:

5) Stick - Forward Into Turn Needle (Forward & Full Lateral)

If Yaw Rate Still High ( > 90 deg/sec )

6) Program Stick aft (Aft and Full Lateral)
7) Activate Roll SAS

** When Yaw Rate Decreases, ( < 90 deg/sec )

8) Slowly, Program Stick Forward (Forward and Full Lateral)

If Recovery Indicated ( -Gx unload, yaw rate < 30 deg/sec )

9) Stick - Forward/Neutral Lateral (break AOA)
10) Controls - Neutral
12) Recover at 17 units AOA

The slight interpretation of NATOPS procedures proven successful in this experiment was the return to low yaw rate NATOPS procedures as the yaw rate decreased below 90 deg/sec, all other procedures were as stated in the "bold-face" NATOPS (NAVAIR-01-F-14AAA-1, section 5; "Upright Departure/Flat Spin") or in applicable NATOPS notes for F-14A flat spin recovery.

RECOVERY CONDITIONS

Fully-developed flat spins were recognized by the flat attitude (approximately 10 deg nose down with no pitch or roll oscillations), steadily increasing yaw rate and longitudinal acceleration (up to 180 deg/sec and -6.5 Gx, eyeballs-out g), and the angle-of-attack remaining pegged at 30 units. Recovering from a flat spin is a difficult task, therefore during this experiment the effect of the following variables on that task were evaluated:

1) -Gx
2) Harness Locked
3) Roll SAS ON
4) Throttle Friction

<u>-Gx</u>

The variable -Gx was varied from -2 to -5 G's during this experiment. All pilots performed spin entries and recoveries within these limits. Under -Gx all objects in the cockpit including the pilot and his flight controls are heavier due to the G-force pushing them forward. All the pilots agreed, that as -Gx increased so did their difficulty in recovery control input (4.3 avg. pilot rating for difficulty). This increase in difficulty may also be shown by the increase in altitude loss as -Gx increases as shown in figure 6. The altitude lost during recovery increases from the -3 Gx missions to the -4 Gx tests (the decrease in altitude loss from -4 Gx to -5 Gx is due to the Roll SAS variable, not -Gx).

A typical pilot comment describing the effects of -Gx is:

> "Good training to experience workload under
> negative g (-Gx):
> -2.0g's = relatively mild
> -4.0g's = relatively heavy"

The only aid for the pilot against -Gx during this experiment was the prompt locking of the harness restraint system upon spin entry. This is the same condition that F-14A pilots are currently operating under.

<u>Harness Locked</u>

A pilot under -Gx is pulled foward, up and out of his seat, if his harness is unlocked. This position can increase the difficulty of performing flight control actions. Participants in this experiment were asked to perform all but one flat spin mission of -3 Gx or less with their harness unlocked and lock it upon spin entry (spins of -4 Gx and greater had the pilot's harness locked constantly throughout the mission). The one -3 Gx flat spin entry and recovery in which the harness was unlocked resulted in a longer recovery time than that of the -3 Gx harness locked flat spin, as shown in Figure 7. The pilot ratings indicate that a locked harness is essential for a successful recovery under high -Gx conditions (the need to lock the harness received a 5.0 average pilot rating for usefulness). A typical pilot comment on the need to lock the harness is:

> "Excellent training for aircrew, because
> a) -5Gx experience is a must
> b) -3Gx unrestrained is a must because,
> 1) Can only use <u>1</u> hand for controls
> 2) You can't get to throttles or roll SAS because your other hand is on the glare shield. ..."

<u>Roll SAS ON</u>

If the pilot is capable of applying the proper recovery controls under the -Gx conditions of a flat spin, the aircraft must also have sufficient altitude to allow the flat spin to deccelerate to 0 deg/sec before it reaches 10,000 feet. As stated in NATOPS (NAVAIR-01-F-14AAA-1, section 5; "Upright Departure/Flat Spin"), the activation of Roll SAS during high yaw rate flat spins reduces the number of turns to recovery and therefore lessens the altitude lost during recovery. Figure 6 shows the reduction in altitude loss with the activation of Roll SAS during recovery procedures as obtained in this experiment. The pilots in this experiment agreed that Roll SAS can aid in spin recovery (4.2 avg. pilot rating for usefulness), but due to the position and size of the Roll SAS switch in the F-14A cockpit, activation of this switch may be difficult for the pilot under flat spin conditions. The pilot opinions gathered during this experiment support this fact by rating the position and size of the switch as below fair (average pilot rating of 2.0), relative to the ease in switch acquisition during flat spin recovery.

Throttle Friction

During a flat spin if one engine is stalled and both throttles are not kept at idle, an asymmetric (unbalanced) thrust condition will exist. An asymmetric thrust condition is a problem for the F-14A due to the fact that this aircraft has one engine on either side of it's center line (Figure 8). The F-14A aircraft with only one engine operating in a spin will tend to remain in that spin in a direction into the inoperative engine, due to the rotational moment created by the operating engine's thrust. This condition can be avoided if both throttle levers are kept at the idle position, and if proper recovery controls are applied. If the throttles remain at the military power setting, the aircraft will reach a point of equilibrium in which the asymmetric thrust moment rotating it in the direction of the spin or inoperative engine and the recovery controls moment applied in the opposite direction are equal, allowing the aircraft to continue to spin/auto-rotate.

It was observed that the throttle levers in the DFS cockpit advanced from idle to military under -Gx forces of -4 Gx or more creating an asymmetric thrust condition if one engine was stalled. The DFS throttle quadrant forces were found to be within an acceptable range of the F-14A aircraft throttle quadrant forces ( Friction OFF: 0.0 lb - .95 lb (F-14A) vs. 1.25 lb - 2.75 lb (DFS) and Full Friction ON: 11.3 lb - 18.0 lb (F-14A) vs. 11.0 lb - 16.5 lb (DFS)) for this experiment. Two possible solutions to this problem were that the pilot could either manually hold the throttle levers at idle or he could increase throttle lever friction to hold the levers in position, both were evaluated during this experiment.

Participants in this experiment were asked to perform two manuevers to evaluate the effects of throttle quadrant friction on flat spin recovery. The first manuever was a clean F-14A aircraft 1-G entry (harness locked) into a flat spin with an engine stall, with normal friction (pilot's normal operating level). The controls and asymmetric thrust levels were held until -4 Gx was attained then recovery controls were applied. An engine stall and normal friction levels during a flat spin require the pilot to retard the engines to idle and hold the throttle levers in the idle position manually (Figure 9). This requirement of one hand on the throttles made aft stick control input more difficult and activation of Roll SAS a problem. The pilot must release the throttles to activate the Roll SAS and when released the throttle levers would advance producing the asymmetric thrust condition again. The second maneuver was the same type of entry and recovery procedures with the addition of increased throttle lever friction (Figure 10). This addition allowed the pilots to use both hands for control inputs and kept throttle levers/thrust at idle which avoided the asymmetric thrust hazard. Participants in this experiment all agreed (4.0 avg. pilot rating for usefulness) that increased throttle friction did aid in spin recovery. The quantitative results of these maneuvers were that the increased friction condition reduced both time and altitude loss for flat spin recovery as shown in Figures 11 and 12. Therefore, the newest aid to flat spin recovery procedures was identified as throttle friction during this experiment.

## CONCLUSIONS

Of the departures and flat spins observed, the most severe entries occurred when the aircraft had asymmetric thrust. Entries with aircraft loading and/or the Roll SAS activated followed asymmetric thrust closely in contributing to entry severity. Flat spin recovery is difficult, but there are several aids to this task. Of the aids investigated, the one identified as the optimal recovery aid was the locking of the harness restraint system, with Roll SAS activation and increased throttle lever friction remaining as secondary recovery aids. The harness restraint when locked holds the pilot in the appropriate position, under -Gx, so he may apply recovery controls. The activation of Roll SAS on the other hand, increases the maximum differential tail deflection from seven degrees to twelve degrees, thereby increasing the aerodynamic effectiveness of the aircraft's control surfaces during recovery. Increased throttle lever friction during recovery is only an aid if one engine has stalled. Increased friction holds the throttles in idle until the in-operative engine can be re-lit upon spin recovery and avoids the hazards of asymmetric thrust. All the pilots of this experiment were capable of recovering the simulated F-14A from the gamut of departures and spins by following NATOPS procedures and using the recovery aids mentioned above.

## RECOMMENDATIONS

Due to the limited nature of the rotary balance data used during this experiment, no flat spin procedural changes are recommended at this time. However, three recommendations, two hardware and one NATOPS modification are proposed, based on the results of this experiment and pilot comments. The first hardware modification recommedation is to add an extension to the Roll SAS switch to make it easier to find and engage during a flat spin. The second hardware modification recommedation is to install a negative Gx automatic locking harness restraint system as soon as possible. The new restraint system would consist mainly of adding a restraint reel that would lock in position at -.85 Gx, as evaluated during reference 6. This new restraint system would not only aid in recovery but would also put the pilot in a better position to initiate ejection procedures. The NATOPS modification proposed is to add the following additional note in the F-14A NATOPS manual under flat spin recovery (NAVAIR-01-F-14AAA-1, section 5; "Upright Departure/Flat Spin"):

> "NOTE: Throttle levers will advance from IDLE to MIL under -Gx conditions unless they are held in place either manually or with increased throttle lever friction. If an engine is stalled this throttle lever motion will complicate recovery by adding asymmetric thrust, which may be severe enough to cause auto-rotation. Recovery under stalled conditions may be impossible until throttles are held in place."

The flat spin/departure environment is a dangerous one and a pilot needs all the help he can get to safely eject from or recover his aircraft, these recommendations will provide some of the help he needs.

## REFERENCES

1. Weber, LT C. L., et al Final Report, Model F-14A Airplane High Angle of Attack Flying Qualities Evaluation. Report No. SA-C11R-77, Naval Air Test Center, Patuxent River, MD, 20 December 1977.

2. Eyth, J., Gleisner, LT D. USN, "Application of the Dynamic Flight Simulator (DFS) to Evaluate Pilot Performance in a Simulated F-14 Flat Spin Environment," Paper No. 85-1730, AIAA Flight Simulation Conference, St. Louis, MO, July 1985.

3. Crosbie, R. J., Eyth, J., Thomas, G. T., et al NAVAIRDEVCEN Dynamic Flight Simulator F-14 Spin Simulation Program System Description and Specification Report. Report No. NADC-81145-60, Naval Air Development Center, Warminster, PA, April 1981.

4. F-14A NATOPS Flight Manual. NAVAIR-01-F-14AAA-1 December 1982 with current changes.

5. Bischoff, D. E., Poole, D. A., Eyth, J., "Flight Simulation Fidelity in a Total G-Force Environment," Paper No. 85-1741, AIAA Flight Simulation Conference, St. Louis, MO, July 1985.

6. Eyth, J., Gleisner, LT D. USN Draft Report, Dynamic Flight Simulator F-14 Spin Recovery Program. Report No. NADC-85126-60, Naval Air Development Center, Warminster, PA, 1 August 1985.

Data Collection Test Matrix for F-14A Departure/Spin Investigation

1. DEPARTURES:

| Loading | Trim | Entry | Thrust |
|---|---|---|---|
| Clean | 250 | Accel RSAS-OFF | Mil |
| Clean | 250 | Accel RSAS-ON | Mil |
| Clean | 250 | Accel RSAS-OFF | Mil-Stall |
| 2X4 Loading | 250 | Accel RSAS-OFF | Mil |

2. SPINS:

| Loading | Trim | Harness | Entry | Thrust | Dir | Gx | Recovery |
|---|---|---|---|---|---|---|---|
| 2X4 | 120 | Unlock/LOCK | 1-G | Mil | LT | -3 | NATOPS-RSAS OFF |
| CLEAN | 250 | Unlock/LOCK | Accel | Mil | RT | -3 | NATOPS-RSAS OFF |
| CLEAN | 120 | LOCK | 1-G STALL | Mil | RT | -4 | NATOPS-RSAS OFF NORMAL FRICTION |
| CLEAN | 120 | LOCK | 1-G STALL | Mil | LT | -4 | NATOPS-RSAS OFF INCR. FRICTION |
| CLEAN | 250 | LOCK | Accel | Mil | RT | -5 | NATOPS-RSAS ON |
| CLEAN | 250 | UNLOCK | Accel | Mil | LT | -3 | NATOPS |

(Typically, each pilot received the same sequence of entry and Gx conditions. Loading, direction, displays, and recovery Roll SAS conditions be varied to complete the data matrix.)

Figure 1: Test Matrix for F-14A Departure/Spin Investigation

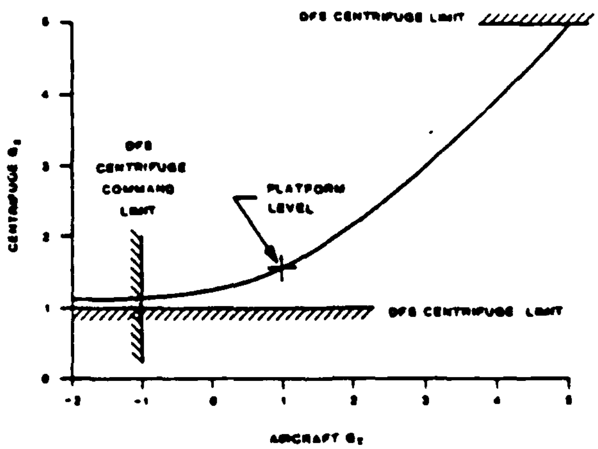


Figure 2: Centrifuge Gz Command Function

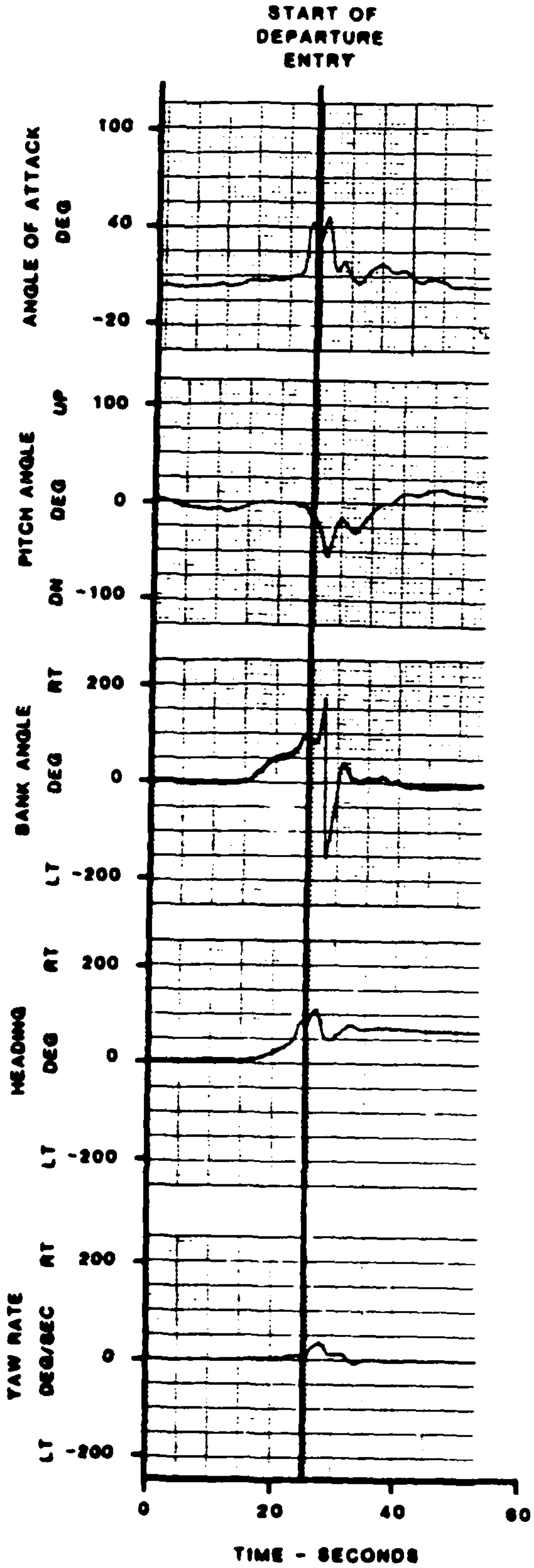


Figure 3: Typical Departure
Experience

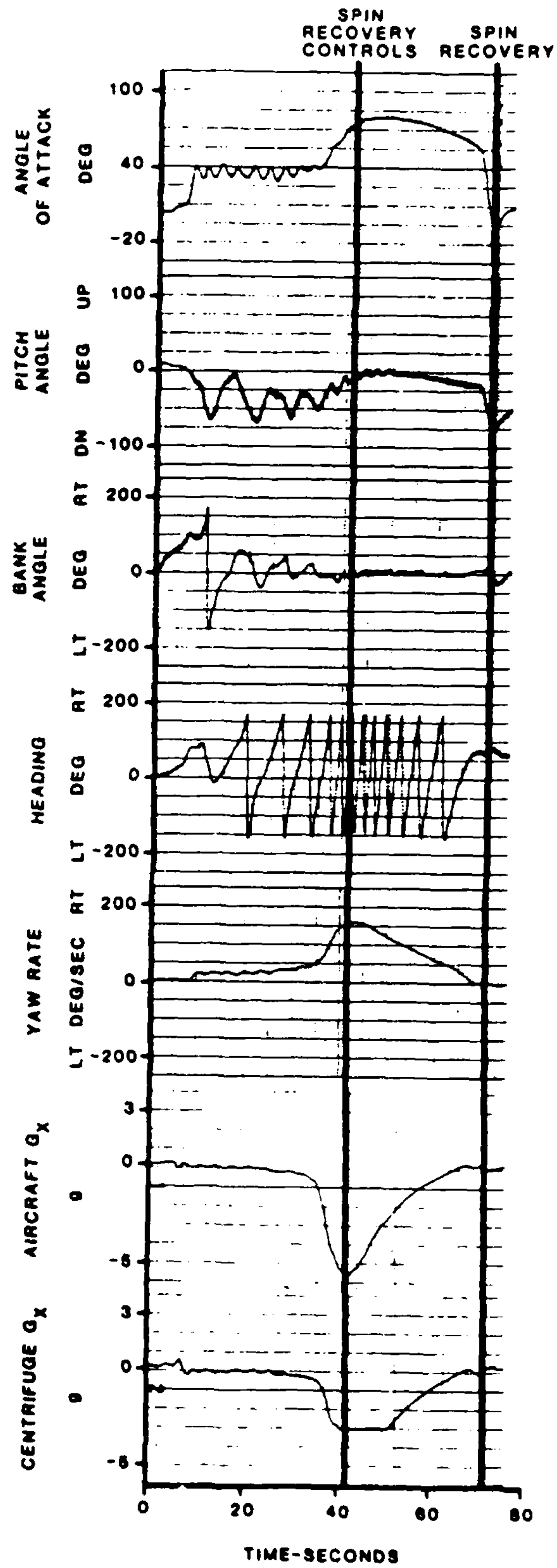


Figure 4: Typical Flat Spin
Experience

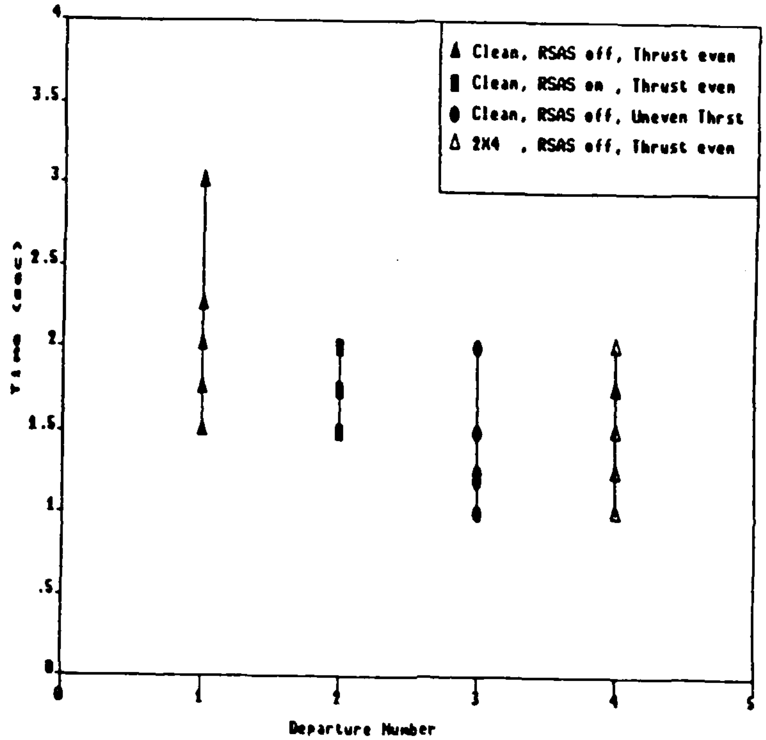


Figure 5: Departure Severity Results

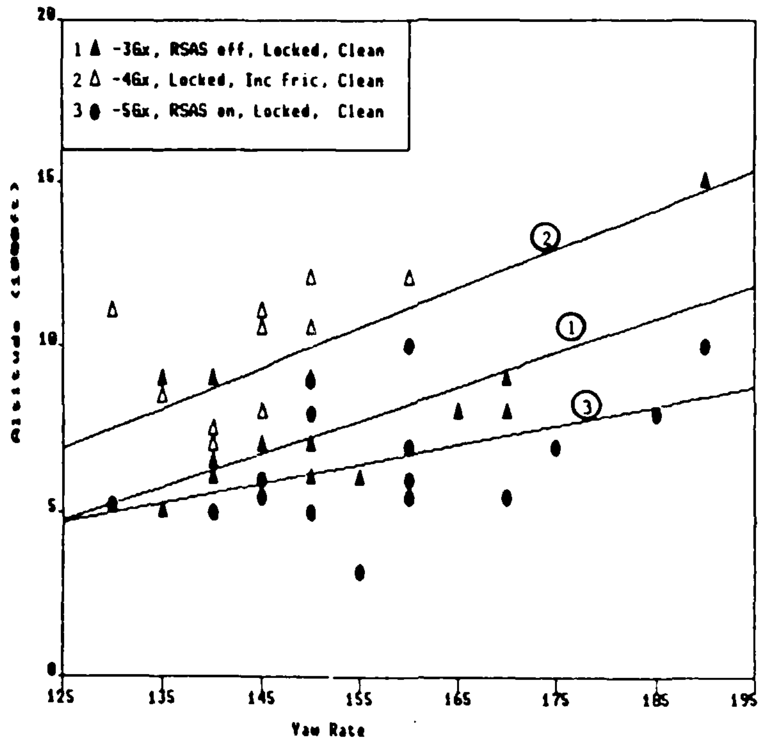


Figure 6: Flat Spin Experience Altitude Losses

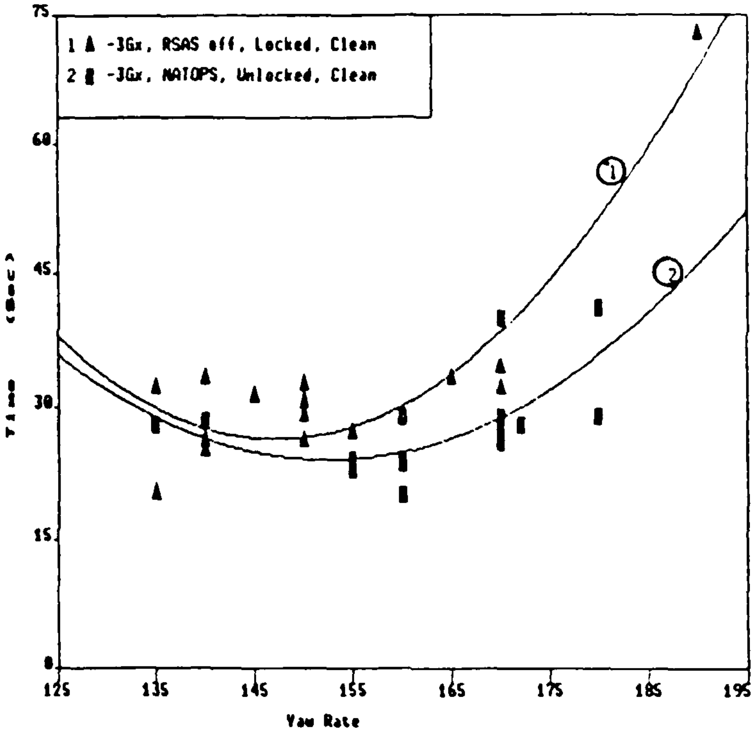


Figure 7: Harness Lock: Recovery Times

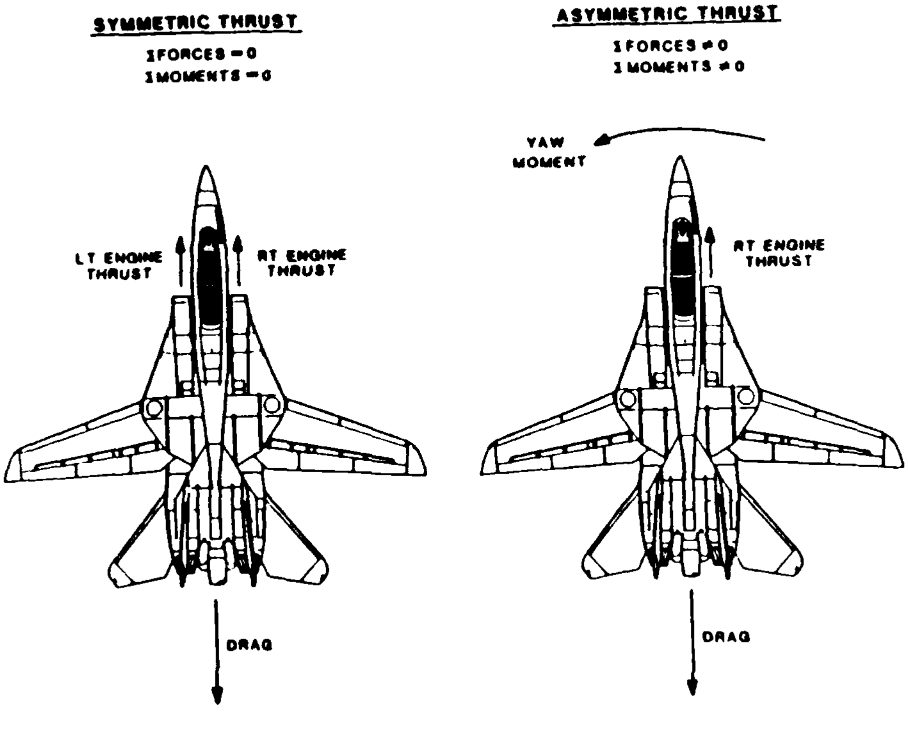


Figure 8: F-14A Aircraft

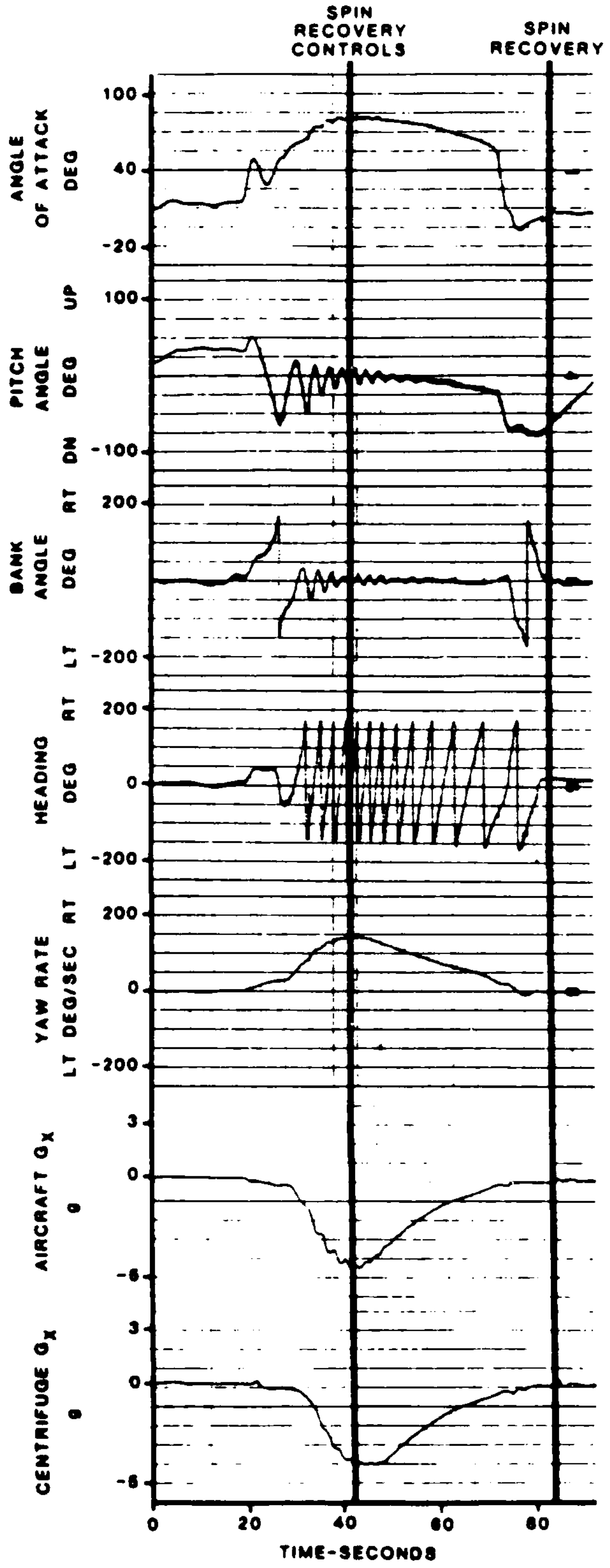


Figure 9: -4Gx Flat Spin with Normal Throttle Friction

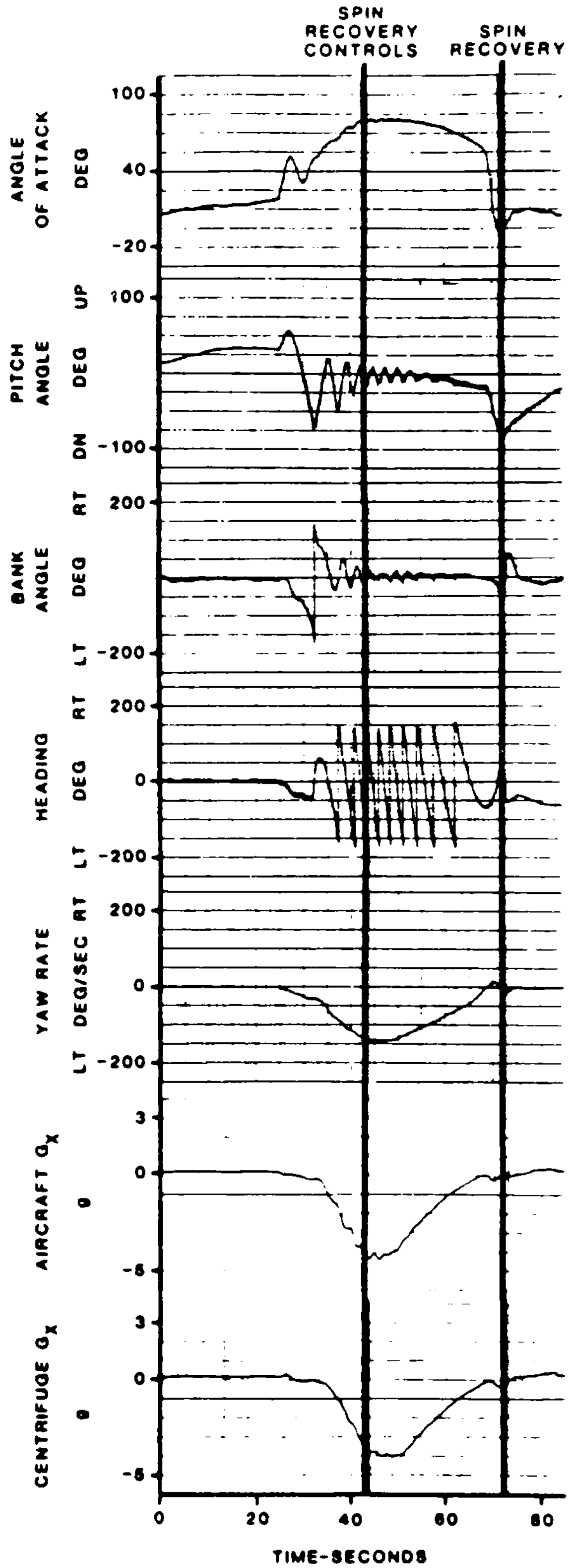


Figure 10: -4Gx Flat Spin with Increased Throttle Friction

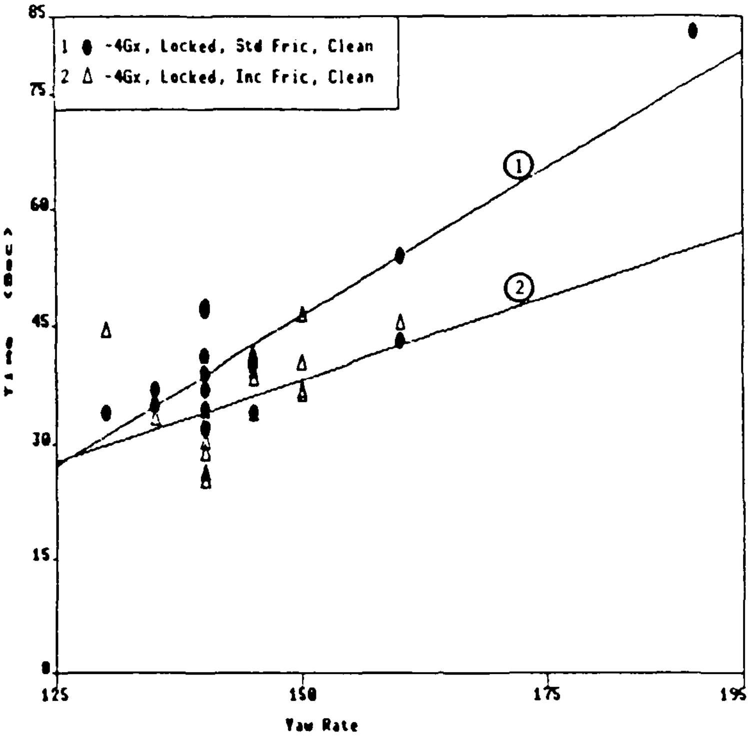


Figure 11: Throttle Friction: Recovery Times

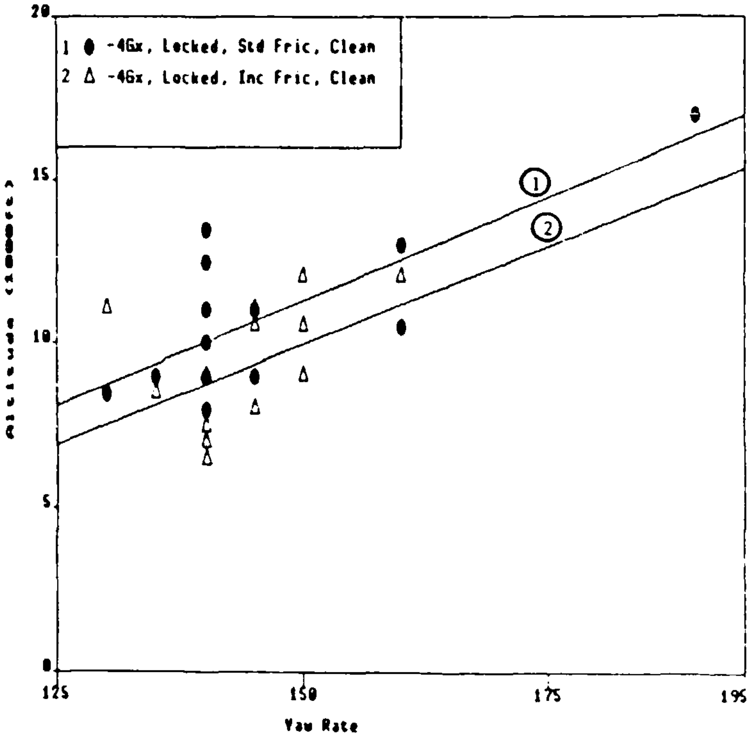


Figure 12: Throttle Friction: Altitude Losses

# APPENDIX A

# PILOT QUESTIONNAIRE

DFS F-14A Spin Investigation

October 1986

Debriefing Guide

BIOGRAPHICAL DATA

Rank/Name ______________________________ Date __________

SSN ______________ Age ______ Squadron ________________

Work Address ______________________________________

Phone Number ______________________

| Flight Time: | All Aircraft | F-14 |
|---|---|---|
| Total | ______ hrs | ______ hrs |
| Last 60 Days | ______ hrs | ______ hrs |

| Simulator Time: | 2F95 | 2E6 | 2F112 |
|---|---|---|---|
| Total | ______ hrs | ______ hrs | ______ hrs |
| Last 60 Days | ______ hrs | ______ hrs | ______ hrs |

Have you had any spin training?

When? ______________________________________

Where? ______________________________________

What Type? (Aircraft, Simulator, Classroom, etc.)

______________________________________

Have you ever entered an unintentional spin in an F-14? YES NO

What were the circumstances? ______________________________

______________________________________

I. DEPARTURES:

A. How do you define departure? ________________________________________

______________________________________________________________________

B. What was the severity of departure?

F-14:

Roll SAS ON entry

Mild 1 2 3 4 5 Severe

Roll SAS OFF entry

Mild 1 2 3 4 5 Severe

Store (2X4)

Mild 1 2 3 4 5 Severe

Asymmetric Thrust

Mild 1 2 3 4 5 Severe

II. SPINS: Maximum -Gx experienced -3, -4, -5, -6

A. What was the severity of spins?

F-14:

Clean

Mild 1 2 3 4 5 Severe

Stores (2X4)

Mild 1 2 3 4 5 Severe

Asymmetric Thrust

Mild 1 2 3 4 5 Severe

II. SPINS (continued)

B. What effect did the following items hane on your recovery?

Throttle Friction (≥ -4 Gx w/ Asymmetric Thrust)

ineffective 1 2 3 4 5 very effective

Roll SAS On

ineffective 1 2 3 4 5 very effective

Harness Lock (> -3 Gx)

useless 1 2 3 4 5 very helpful

-Gx on Recovery Control Input

lessened difficulty 1 2 3 4 5 increased difficulty

III. GENERAL:

A. Roll SAS switch position and size, relative to ease in acquisition during manuever:

poor 1 2 3 4 5 excellent

B. Should throttle friction be increased with recognition of a flat spin?

YES NO

If yes, how important should the increase in friction be in NATOPS recovery procedures? (Sec. 5-39)

not at all 1 2 3 4 5 very important

C. Would you recommend others receive this exposure? YES NO

If yes, how often?
1 once every 4 months
2 once a year
3 once a tour
4 once
5 other: ______________________

III. GENERAL (continued):

Who? (type) 1 Student pilots 4 Fleet pilots (F-14 only)

2 Instructors 5 All Fleet pilots

3 Test pilots 6 Other:________________

D. Did any of the DFS characteristics detract from your spin familiarization?

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

E. What, if any, modifications would you recommend to hte DFS simulation to improve its fidelity, usefulness, realism, etc.?

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

F. Other comments?

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